ORGANIC MANURE FROM SEWAGE, TOWN REFUSE AND WASTE VEGETATION.

By J. Jagannatha Rao and V. Subrahmanyan.

The problem of utilising waste has received attention from the earliest times. In ancient China and Japan, conversion of different forms of farm and domestic waste into manures was a recognised item of agricultural practice (King, Farmers of Forty Centuries, 1911). In more recent times, various other methods such as feeding to hogs, extraction for fat (*Amer. J. Pub. Health*, 1912, **2**, 937; *J. West. Soc. Eng.*, 1929, **34**, 102), incineration for development of energy (*Eng. News Rec.*, 1923, **91**, 844; *J.S.C.I., Rev.*, 1927, **5**, 119), and the manufacture of cement, building stones (Kershaw, B. P., 149,033 of 1919) and various types of glasses (*Compt. rend.*, 1924, **178, 1161**) have been developed, but most of them are inapplicable to the commoner types of refuse which contain very little fat or other extractable matter and are not readily combustible (Clemesha, Sewage Disposal in the Tropics, 1910, 230). In view of the above and the readiness with which they undergo decomposition in presence of suitable chemical and biological starters, composting has been recognised to be the most suitable method of utilising waste materials particularly in the tropics where the soils are naturally deficient in carbonaceous matter and respond readily to treatment with organic manures.

Scientific study of the subject did not, however, receive much attention until Russell and Richards (*J. Agric. Sci.*, 1917, **8**, 495) and later, Richards and Hutchinson (*J. Min. Agric.*, 1921, **28**, 398) investigated the nature of the transformations attending the decomposition of straw in presence of different forms of nitrogen. Subsequent contributions by Rege (*Ann. Appl. Biol.*, 1927, **14**, 1), Norman (*Biochem. J.*, 1929, **23**, 1353, 1367; *Ann. App. Biol.*, 1930. **17**, 575) and Jensen (*J. Agric. Sci.*, 1928, **19**, 71) in England, Waksman. Starkey and their co-workers in America (*Soil Sci.*, 1927, **24**, 275, 317: *Ibid.*, 1928, **26**, 113, 155, 239; *Ibid.*, 1929, **27**, 271, 319, 355, 389, 433; **28**, 55; *J. Amer. Sci. Agron.*, 1929, **21**, 795) and Krantz, Gerlach, Ruschman, Löhnis and others in Germany (*Nature*, 1927, **122**, 339; *Z. pflanz. Dung.*, 1928, **B8**, 303, *Ibid.*, 1929, **A13**, 208; *Ibid.*, **B8**, 529; *Ibid.*, **B9**, 268; *Zentralbl. Bakt.*, 1928, **II 75**, 405; *Ibid.*, 1929, **II 77**, 216) have helped to throw further light on the decomposition of cellulosic materials in the manure heap.

In India, a considerable amount of work on the preparation of organic manures from waste materials was carried out by Hutchinson and his assistants at Pusa (*Agric. Res. Inst., Pusa*, Bull., 1914, **46**, *et. seq.*), Howard and Wad at Indore (The Waste Products of Agriculture, 1931), Carberry and Finlow in

Bengal (*Agric. J. India*, 1928, **23**, 80), Clarke and his associates at Shajahanpur (*Proc. Indian Sci. Cong.*, 1930, **17**, 23), Viswanath and his co-workers at Coimbatore, Coleman and his staff in Mysore and Fowler and his students at Bangalore, Nasik and Cawnpore (*Agric. J. India*, 1930, **25**, 369).

Although a considerable measure of success has already been achieved, yet the precise chemical and biological mechanism of the decomposition changes, particularly in heterogeneous masses like town refuse, has not yet been fully investigated. Moreover, further work has to be carried out on the standardisation of conditions for the (*a*) most efficient conversion of the different organic components into plant nutrients, (*b*) suppression of foul odours and destruction of putrefactive and pathogenic organisms and harmful insects, (*c*) fixation of atmospheric nitrogen, evidence for which has been adduced by some of the previous workers (*e.g.*, Howard and Wad, *loc. cit.*; Fowler, *loc. cit.*), (*d*) minimisation of loss of organic matter and preservation of nitrogen both during and after completion of the decomposition, and (*e*) application of the manure to land with and without addition of mineral fertilisers. The present investigation was, therefore, undertaken to elucidate the above and related problems.

Experimental.

Preliminary trials in pots.—To standardise conditions for the experimental heaps. trials were made with powdered town refuse in glazed, non-draining, earthenware pots. The refuse (½ lb.) was loosely packed and the pots divided into 3 sets which were treated as follows:—(*a*) Control (untreated), (*b*) mixed uniformly with chemicals (ammonium sulphate, 7 g.; rock phosphate containing 26 per cent. P_2O_5, 2 g.; and burnt lime 8 g.), (*c*) treated with chemicals as in *b plus* 50 c.c. of activated sludge (15 per cent.) as biological starter. The contents of the different sets were moistened with varying proportions of raw sewage or effluent from the activated sludge tank and the decomposition changes followed from day to day. It was soon observed that the finely divided refuse was exceedingly difficult to work, owing to its tendency to cake. Aeration was seriously hampered and if the material was not stirred frequently decomposition slackened with attendant bad smell, flies and mosquitoes.

Putrefactive organisms and harmful insects were suppressed by spraying the contents of the pots with small amounts (50 c.c.) of solutions containing (*a*) bleaching powder (aqueous suspension containing 0·3 per cent. chlorine), or (*b*) dilute Bordeaux mixture (containing $CuSO_4$ $5H_2O$, 0·06 per cent. and lime 6·0 per cent.). It was also noted that the decomposition was most rapid in pots treated with activated sludge and subsequently sprayed with copper-lime mixture, the decomposing materials developing a characteristic dark colour; while a microscopic examination of the cellulosic fibres showed that they were undergoing more rapid physical disintegration.

In view of the foregoing observations, further trials were made with specimens of whole refuse after treating it with chemicals and activated sludge as in experiment *c*: the decomposition, as indicated by loss in dry matter, proceeded more rapidly under such conditions than when the refuse was finely divided. No foul odours were evolved and there was less need for either stirring or spraying with insecticides and fungicides. The disintegration of fibrous materials, however, appeared to proceed faster in presence of copper-lime mixture than otherwise.

In order to determine whether the increased darkening observed in the case of specimens sprayed with the copper mixture was due to more intensive humification, or to some product of reaction of either copper or lime, or of both combined with some of the decomposing materials, specimens were treated as follows:—(*a*) Control (untreated), (*b*) sterilised by autoclaving and sprayed with (1) suspension of lime, (2) solution of copper sulphate, and (3) copper-lime mixture. It was observed that specimens *b* (2) and (3) were distinctly darker than the others and that the colour tended to deepen on standing, showing that the colour change was due to a chemical reaction of copper and not to increased humification.

Trials in heaps.—Refuse was collected from busy streets in Bangalore City and was heterogeneous, containing non-decomposable or resistant glass, tins, bones, feathers, etc., with readily putrefactive kitchen waste and night-soil.

Sampling for analysis was done by collecting representative specimens from different parts of the mixed heaps, combining the small lots thus obtained, then crushing them to fine division, and finally collecting specimens as for soil examination. The average percentage decomposition of the oven-dried material as determined by the A. O. A. C. (1925) methods was as follows:—Loss on ignition, 64·7: total nitrogen, 0·69: total phosphorus (as P_2O_5), 0·40: total potash (as K_2O), 0·19. The daily collections spread over a number of days were first mixed together, then divided into 16 small heaps each weighing about half a ton. The heaps were piled on plots of land 12 ft. square separated from each other by a drain 1 ft. wide and 1 ft. deep. They were then treated with different chemical and biological starters (Table I), the actual quantities of the different ingredients being so adjusted as to correspond to 0·1 per cent. of nitrogen, and 0·03 per cent. each of K_2O and P_2O_5 on the original dry weight of the material. The heaps were moistened from day to day with either raw sewage or effluent from the activated sludge tank, 60 gallons of each fluid being sprayed in the morning and evening of each day. The heaps were thoroughly stirred three times a day to ensure complete aeration.

After the third day, the heaps emitted unpleasant odours and harboured numerous flies, mosquitoes and other insects which were effectively suppressed by spraying with thin suspensions of either copper-lime mixture (*loc. cit.*) or bleaching powder suspension (*loc. cit.*), no more than 4 litres of each being required per heap: dusting with cyanamide was not so satisfactory, and the foul odour persisted although the treatment was repeated at frequent intervals. The scheme of treatments may be stated briefly as follows;—

TABLE I.

Heap No.	Nitrogen as	Phosphoric acid as	Insecticide
1	Act. sludge + R. S.	Rock phosphate	Bleaching powder
2	CaNCN + do.	do.	Bordeaux mixture
3	R. S. only	do.	do.
4	R. S. + CaNCN	do.	CaNCN
5	$(NH_4)_2SO_4$ + R. S.	Superphosphate	Bordeaux mixture
6	$NaNO_3$ + R. S.	do.	do.
7	Effl. only	Nil	Nil
8	$NaNO_3$ + Effl.	Rock phosphate	Bleaching powder
9	$(NH_4)_2SO_4$ + do.	do.	Bordeaux mixture
10	do. + do.	do.	do.
11	CaNCN + do.	do.	Bleaching powder
12	$NaNO_3$ + do.	Superphosphate	do.
13	$NaNO_3$ + CaNCN + Effl.	do.	CaNCN
14	$(NH_4)_2SO_4$ + Effl.	do.	Bleaching powder
15	Act. sludge + do.	do.	do.
16	CaNCN + do.	do.	CaNCN

R.S.=Raw sewage; Effl.=Effluent from the activated sludge tank. All the heaps were treated with potassium sulphate corresponding to a potash (K_2O) content of 0·03 per cent.

The commercial specimens used for the above treatments were analysed for the percentages of their active constituents:—K_2O in potassium sulphate, 38·3; P_2O_5 in superphosphate, 29·3; P_2O_5 in rock phosphate, 26·0; N in ammonium sulphate, 20·89; N in sodium nitrate, 16·2; N in cyanamide, 18·1; CaO in burnt lime 63·5. The raw sewage used for spraying had an average nitrogen content of 4 parts per 100,000 and the effluent, 2 parts per 100,000.

Loss of organic matter during decomposition.—This was determined indirectly as follows. Representative specimens of the decomposing material were collected at stated intervals and the ash-contents determined on the oven-dry basis. Hence the corresponding changes in organic matter were calculated, assuming that during decomposition the total ash constituents remain unaltered and that the increase in ash percentage noticed at the time of observation is really due to a corresponding loss in organic matter. Thus if X represents the initial ash percentage, then the corresponding amount of organic matter (as represented by loss on ignition) would be 100—X: if at the time of observation the ash percentage is represented by Y, and if Z be the unknown loss in organic matter, then,

$$\frac{100\,[\,(100-X)-Z\,]}{100-Z}=100-Y$$

which, on solving, gives

$$Z=\frac{100\,(Y-X)}{Y}$$

in which both X and Y are known. Table II represents the figures thus determined for the different heaps.

TABLE II.

Heap No.	Percentage loss in organic matter in		
	20 days	35 days	70 days
1	11·3	13·4	20·1
2	13·0	15·5	19·5
3	12·4	14·7	21·2
4	10·4	13·6	20·8
5	11·7	14·8	20·3
6	13·0	15·9	21·2
7	9·7	11·3	14·9
8	10·6	13·9	21·2
9	12·6	15·3	20·1
10	11·9	14·8	21·0
11	11·3	14·1	19·7
12	11·0	13·0	19·7
13	10·8	13·2	21·5
14	10·3	13·9	20·1
15	11·0	13·4	21·2
16	10·6	13·0	20·6

Analyses (unrecorded) of representative specimens at the end of 60 days had shown that the loss in organic matter was about 20 per cent. from every one of the heaps with the exception of No. 7. Since 10 days later, the organic matter was found to have suffered no further loss, it was concluded that further decomposition, if any, would be very slow and the corresponding loss of organic matter almost negligible. Further spraying with sewage was therefore stopped, the contents of the heaps air-dried and the material thus obtained used for further chemical analyses and vegetation experiments.

It was noted in the case of the heap (No. 7) that had been treated with effluent alone that most of the cellulosic materials remained intact, rigidity of the fibrous substances suggesting very poor decomposition. In the case of the others the physical breakdown had proceeded very much farther; even those substances which retained their shape crumbled readily on crushing. The effect was most marked in heaps 1 and 15 which had previously been treated with activated sludge. Those specimens were darker than the others and were readily friable on gentle pressure; although their organic contents were the same their physical condition suggested that these would be more readily available for plant nutrition than the others.

Chemical composition of the preparations.

Nitrogen distribution:—This was determined on the oven-dry basis according to the A.O.A.C. (1925) methods, and the results shown in Table III.

TABLE III.

Heap No.	Nitrogen per cent.			
	Total	Albuminoid	Ammonia	Nitrate
1	1·70	0·57	0·17	0·24
2	1·17	0·55	0·15	0·20
3	1·21	0·35	0·04	0·14
4	0·96	0·35	0·06	0·11
5	0·96	0·43	0·14	0·15
6	1·08	0·39	0·01	0·15
7	0·81	0·44	0·03	0·05
8	1·20	0·36	0·06	0·10
9	1·12	0·38	0·09	0·23
10	0·92	0·29	0·03	0·07
11	0·90	0·31	0·05	0·07
12	1·02	0·48	0·04	0·09
13	0·96	0·41	0·08	0·09
14	0·87	0·30	0·05	0·06
15	1·47	0·47	0·05	0·23
16	0·90	0·38	0·05	0·07

Considering the heterogeneity of the materials and the inevitable error in sampling, the differences between the nitrogen contents of most of the heaps are not significant. The two heaps originally treated with activated sludge (1 and 15) were exceptions and contained larger quantities than the others. The heap that had received its nitrogen from the effluent alone was apparently the poorest, but the percentage was not very much lower than those of some others. The heaps sprayed with raw sewage are on the average slightly richer in nitrogen than those receiving effluent, but the difference is not very considerable.

Distribution of nitrogen into the different forms shows no striking relation traceable to the previous treatment except in the case of No. 1 (activated sludge) which is richer in all the constituents than the others: nor could a special advantage be claimed for any of the nitrogenous starters excepting activated sludge.

Nitrogen balance.—Previous workers have reported losses of nitrogen ranging from 10–40 per cent. of the total either during the preparation or storage of organic manures. The extent to which such losses occur during either fully ærobic conditions or strictly anærobic ones is still obscure (Barrit, *Biochem. J.*, 1931, **25**, 1965). In composting experiments it is very difficult to maintain exclusively ærobic or anærobic conditions, and there is generally a combination of both; material either exposed to air or near the surface is under partly ærobic conditions while the interior, particularly when the heaps are not turned frequently, would tend to be anærobic. In the present investigation the conditions were maintained as nearly ærobic as possible by turning the heaps at least three times a day.

To determine the effect of different treatments, as also the related air conditions on the nitrogen balance of the decomposing heaps, the total quantities of nitrogen originally present in, subsequently added to and finally present in the various heaps were calculated, and the ultimate gain or loss estimated (Table IV).

TABLE IV.

TOTAL NITROGEN.

Heap No.	Weight of heap in lbs. Initial	Final	Total Nitrogen Originally in the refuse		Added as chemicals and/or sprayed as sewage		Expected in the final product		Found in the final product		Gained (+) Lost (—) percentage			
			lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.		lb.	oz.	
1	973	777	7	1	4	5	11	6	13	4	(+)	1	14	- 16.5
2	744	599	5	7	4	3	9	10	7	0	(—)	2	10	—27.3
3	1,086	856	6	11	4	7	11	2	10	6	(—)	0	12	— 7.0
4	1,534	1,215	9	6	4	13	14	3	11	11	(—)	2	8	— 17.6
5	1,005	801	7	5	4	6	11	11	7	11	(—)	4	0	—34.2
6	1,013	798	7	6	4	6	11	12	8	10	(—)	3	2	—26.6
7	1,370	1,166	8	5	3	0	11	5	9	7	(—)	1	14	—16.6
8	700	552	5	1	2	5	7	6	6	10	(—)	0	12	—10.2
9	708	566	5	2	2	6	7	8	6	5	(—)	1	3	—15.8
10	1,205	952	8	12	2	12	11	8	8	12	(—)	2	12	— 23.9
11	990	795	7	2	2	9	9	11	7	2	(—)	2	9	—26.5
12	753	605	5	7	2	6	7	13	6	3	(—)	1	10	—20.7
13	863	675	6	6	2	7	8	13	6	8	(—)	2	5	—26.2
14	1,502	1,200	10	14	3	0	13	14	10	7	(—)	3	7	—24.8
15	690	544	5	1	2	5	7	6	8	0	(+)	0	10	+ 8.5
16	984	781	7	1	2	9	9	10	7	0	(—)	2	10	—27.3

It will be seen that there was distinct loss (7·0—34·2 per cent.) of nitrogen from the majority of heaps, and this could not be related to the treatment; but there appears to be a marked loss from all heaps receiving mineral starters irrespective of their chemical nature.

The significance of the foregoing observations will be appreciated on realising that the organic manures under investigation are worth at least Rs. 5 (*7s. 6d.*) per ton, and since they contain (approximately) 1 per cent. nitrogen, the latter represents about As. 4 (*4½d.*) per pound. The losses range from 12 oz. to 4 lbs. of nitrogen and correspond to As. 3. to Re. 1 per heap. As the average weight per heap is about 1000 lbs. and the corresponding loss of nitrogen, 2 lbs., it may be reckoned that the equivalent monetary loss will be Rs. 1-4-0 (about *2s.*) on the preparation of each ton of manure. The extent to which town refuse becomes available depends on the occupation and habits of the citizens and the efficiency of collection. It may, however, be assumed that the daily collections will correspond to about 1 ton per 1000 of population. About one-sixth of India's population live in towns or villages with organisation for the collection of refuse, so that the annual collections, and the manure that could be prepared from them may be rated at 20 and 15 million tons, respectively. The above figures, while illustrating the enormous potential manurial wealth in the refuse of India, also show that the nitrogen-loss would be equivalent to no less than 150 lakhs of rupees (over one million pounds) on the finished product. The foregoing figures educe the importance of the organic manure industry and indicate the need for further efforts to minimise loss of nitrogen during preparation.

As exceptions to the above, heaps 1 and 15 show distinct nitrogen-gains of 16·5 and 8·5 per cent. respectively, thereby suggesting fixation of atmospheric nitrogen: both having been similar to the others except in treatment with activated sludge, the results indicate that fixation was due to that starter.

Evidence has been adduced by previous workers to suggest that fixation of atmospheric nitrogen may occur in manure heaps (*e.g.*, Tottingham, *J. Biol. Chem.*, 1916, **24**, 221). Richards noticed marked fixation during decomposition of horse-fæces in presence of calcium carbonate, and showed that the fixation was effected by a mixed culture of *azotobacter* and *B. lactis ærogenes* (*J. Agric. Sci.*, 1917, **8**, 299). Fowler observed that nitogen-fixing bacteria are present in activated sludge (*J. Indian Inst. Sci.*, 1921, **3**, 227), and noted that when biochemical starters were employed, there was positive increase in total nitrogen thereby suggesting fixation from the atmosphere (*Agric. J. India*, 1930, **25**, 363). Recently, Howard and Wad obtained similar evidence with respect to their Indore method (*loc. cit.*). In the light of the foregoing observations, it appears that under favourable conditions the original nitrogen can be retained and fresh quantities of that element be fixed from the atmosphere.

The technique of biological fixation has yet to be standardised: further work is needed to confirm the present observations on a more extensive scale with various types of raw materials, and to determine the various chemical and biological factors relating to fixation. These investigations are now in progress and will form the subjects of later communications.

Available potash and phosphoric acid.—These were estimated by the method of Dyer (*J. C. S.*, 1894, **65**, 115), and the results shown in Table V.

TABLE V.

Heap No.	Availability per cent. of		Heap No.	Availability per cent. of	
	K_2O	P_2O_5		K_2O	P_2O_5
1	0·09	0·27	9	0·08	0·34
2	0·10	0·26	10	0·11	0·22
3	0·09	0·27	11	0·08	0·28
4	0·07	0·24	12	0·13	0·25
5	0·10	0·22	13	0·06	0·24
6	0·05	0·23	14	0·09	0·27
7	0·04	0·20	15	0·11	0·29
8	0·10	0·27	16	0·06	0·33

All heaps contained moderate amounts of both constituents. No particular relation could, however, be traced between any of the treatments and the corresponding availability.

Influence of copper on the active microflora.—It has already been remarked that the decomposition of refuse proceeded at least as fast in heaps sprayed with copper-lime mixture as in those otherwise treated. In view of previous observations (Rege, *loc. cit.*, Norman, *loc. cit.*, Waksman and co-workers, *loc. cit.*) that decomposition of cellulosic materials is due to fungi, and the known fact that copper, even in minute quantities, is inimical to the growth and activity of such organisms, it was considered probable that the fungi present in the copper-treated heaps either became acclimatised to the presence of that element, or that the changes were wrought by other micro-organisms.

To verify the above, platings were carried out on different count media: mannite-asparagin agar for bacteria (*Ann. Appl. Biol.*, 1922, **9**, 241), starch agar for *actinomyces* (*J. Indian Inst. Sci.*, 1929, **12A**, 253) and Czapek's agar for fungi, with specimens of decomposing refuse from heaps treated with (*a*) raw sewage alone, (*b*) raw sewage with different chemicals, and (*c*) raw sewage with different chemicals but sprayed with copper-lime mixture. The observations showed that whereas fungi were the dominant flora in both *a* and *b* and persisted to a late stage in the decomposition, the reverse was the case in heaps treated with copper, where, within four weeks, the fungi diminished considerably while *actinomyces* increased almost six-fold. This suggests that the microflora concerned are profoundly affected by spraying with copper. The above observations are now being extended in the laboratory, not only with varying doses of copper, but also with other physiologically active inorganic compounds such as those of zinc and titanium.

Vegetation Experiments.

Pot-culture trials.—With a view to assessing the relative manurial values of the different preparations, pot-cultural trials were made with ragi (*Eleucine coracana*) during (1) autumn and winter of 1930, and (2) spring and summer of 1931. The pots were of ordinary earthenware and held about 40 lbs. of air-dry soil. They were made up with sand and soil in the usual way with 40 g. (each) of burnt lime, and after about a week were treated as follows:—(*a*) Sixteen sets with the finished products from the different heaps, at the rate of ½ lb. per pot and (*b*) one set each with activated sludge (62 g.), farmyard manure (1 lb.), and complete minerals ($NaNO_3$ 1 g., super 4 g., potassium sulphate 2 g.). One set of pots was also left untreated as control, and five pots were allotted for each treatment. Twelve seeds were sown per pot, and as the experiment progressed, representative plants were collected from each pot, for thinning and to give sufficient material for growth measurements and chemical analyses. From several sets of determinations the following figures obtained at three different stages during one season (1931) will illustrate the relative values (Table VI).

TABLE VI.

Manure from Heap No.	Root-length in cm.			Shoot-height in cm.			Root-weight per plant in g.			Shoot-weight per plant in g.		
	DAYS			DAYS			DAYS			DAYS		
	21	38	52	21	38	52	21	38	52	21	38	52
1	22	35	44	12	48	56	0.04	0.46	1.71	..	0.56	1.92
2	25	40	43	14	47	60	0.04	0.66	1.08	0.07	0.58	1.67
3	22	36	45	11	44	56	0.03	0.41	1.04	0.04	0.60	1.47
4	22	30	55	18	47	55	0.04	0.45	1.44	0.05	0.78	1.06
5	24	27	46	18	50	50	0.06	0.41	1.48	0.01	0.67	1.14
6	21	47	50	14	45	65	0.04	0.84	1.47	0.07	0.61	1.22
7	22	24	27	11	40	40	0.03	0.27	0.55	0.07	0.46	0.46
8	24	28	45	12	43	54	0.05	0.47	1.21	0.06	0.47	1.23
9	24	29	44	15	42	67	0.04	0.51	0.95	0.09	0.82	1.85
10	20	29	44	13	36	46	0.03	0.37	0.92	0.06	0.39	0.57
11	24	29	30	15	39	53	0.07	0.23	0.56	0.02	0.33	0.92
12	24	30	38	14	44	56	0.03	0.50	0.80	0.04	0.63	1.60
13	22	26	46	12	40	54	0.04	0.25	1.17	0.03	0.43	1.09
14	19	40	..	11	38	48	..	0.26	0.44	..	0.40	0.75
15	17	29	47	14	39	61	0.04	0.37	1.11	0.05	0.60	1.75
16	26	37	48	15	46	52	0.05	0.44	0.88	0.06	0.78	0.65
Activated sludge (dry powder) ..	22	33	44	17	53	73	0.05	0.72	1.95	0.14	1.56	3.38
Farmyard-manure..	21	35	44	16	47	73	0.02	0.64	0.75	0.12	0.51	1.25
Complete minerals	19	33	47	7	40	48	0.01	0.29	0.78	..	0.13	0.12
No Manure ..	12	×	×	3	×	×	0.003	×	×	0.002	×	×

.. Data not available. × Plants made poor growth and died prematurely.

No relation could be traced between the root-length or shoot-height and any of the treatments, nor does the root-weight throw any light on plant development. The shoot-weight being that of the portion above ground is a useful index of growth, and being composed largely of those of the tillers, it may also be considered as the index of relative tillering capacities of the plants under various treatments.

The results show that although they are inferior to activated sludge, many of the refuse-manures, particularly those sprayed with raw sewage, are slightly superior to farmyard manure and even more superior to combined chemical fertilisers.

Plot experiments.—The crop yields under field conditions were compared by the foregoing experiments repeated on plots, 10 ft. by 10 ft. and separated by raised ridges of about 1 foot width. Three were allotted for each manurial treatment, and to minimise inherent errors due to soil and other variations, were distributed at random (Fisher, Statistical Methods for Research Workers, 1925). All the plots were first treated with lime at the rate of 2 tons per acre, and after about a fortnight were divided into four groups as mentioned above and treated with (*a*) farmyard manure at 25 tons to the acre, (*b*) organic manure obtained by spraying raw sewage on town refuse on a nitrogen basis equivalent to *a*, (*c*) complete minerals consisting of (1) nitrate of soda at 80 lbs., (2) superphosphate (concentrated) at 4 cwts, and (3) potassium sulphate at

2 cwts. per acre, and (*d*) no manure as control. Ragi seedlings about a month old were transplanted into the plots, and when the crops came to harvest after about three months were removed, and the yields of grain and straw determined (Table VII).

TABLE VII.

Treatment		Yields						Grain / Grain + Straw
	Ears		Grain		Straw			
	lbs.	oz.	lbs.	oz.	lbs.	oz.		
Refuse-manure ..	24	0	8	8	187	8		0·043
Farmyard-manure ..	23	0	8	2	109	2		0·069
Chemical fertilisers ..	21	2	6	6	89	6		0·069
No manure ..	14	2	5	0	76	2		0·062

It may be seen from the above that the refuse-manure is slightly superior to farmyard-manure when applied on an equivalent nitrogen basis. The results compare more favourably with those for chemically fertilised or unmanured plots. The yield of straw from the refuse-manured plots is disproportionately higher than that of grain when compared with those from other plots. The observations suggest either excessive supply of available nitrogen or absence of certain essential manure constituents that would have helped to increase the proportion of grain to straw. Later trials showed, however, that the effect was at least partly due to insufficiency of available phosphorus: when superphosphate was first applied as a basal dressing to the soil, the proportion of grain to straw showed a distinct increase, thus resulting in a higher yield of grain than that recorded in the above table.

Residual value of the refuse-manure.—After removing the first crop the soil was allowed to rest for three months, then ploughed and sown with ragi seedlings as in the previous experiment: the crops were harvested and the yields of grain and straw determined (Table VIII).

TABLE VIII.

Previous treatment	Yield			
	Grain		Straw	
	lbs.	oz.	lbs.	oz.
Refuse-manure	2	15	17	0
Farmyard-manure	1	12	14	3
Chemical fertilisers	0	13	9	14
No manure	1	7	9	0

The results show that the residual value of the refuse-manure is higher than that of the others; the effect would probably have been still more marked if the soils had been given a longer period of rest, as is usual in dry farming practice. Comparison of yields from plots treated with chemical fertilisers and without manure shows that although the plants were of about the same weight (as indicated by the combined weights of straw and grain) in both the cases, the yield of grain was very much less in the former than in the latter. This observation is rather peculiar and further work is needed to elucidate its significance in tropical farm practice.

Copper toxicity to plant life.—It being possible that the copper mixture in some heaps is toxic to plant growth (Brenchley, Inorganic Plant Poisons and Stimulants, 1927), aqueous and saline extracts of specimens from such heaps were prepared and tested for the presence of copper with negative results. This in conjunction with the pot and plot experiments clearly shows that copper as present in the heaps is non-leachable in appreciable quantities, and will not therefore have any deleterious action on plant growth. It should be noted at the same time that the total quantity of copper in the finished manure, even after repeated sprayings, is very small and could not therefore be expected to appear in appreciable quantities in the extracts. Thus, a heap weighing 1000 lbs. would contain only about 25 g. of copper sulphate (0·006 per cent. on the dry weight), and being applied with a considerably larger proportion of lime, all of it may be expected to have turned rapidly into insoluble carbonate.

It is difficult to state whether appreciable quantities of copper would not pass into solution in presence of the organic acids formed under the swamp soil conditions (Subrahmanyan, *J. Agric. Sci.*, 1929, **19**, 627) when the refuse-manure is applied to paddy fields; but even under such conditions, it is probable that the minute quantities released may actually prove beneficial to plant growth. Field observations in America have shown that increased yields can be obtained by giving top dressings of copper sulphate at 50 lbs. per acre (*Florida Agric. Expt. Sta., Bull.* 190, 1927). Quartaroli (*Ann. Chem. Applicata*, 1929, **19**, 467) has adduced evidence to show that copper is ten times as efficient as manganese in promoting plant growth, and has indicated that copper is related to plant life as are vitamins to animal nutrition. Similar observations on the importance of copper to plant growth are due also to Sommer (*Plant Physiology*, 1931, **6**, 339).

Cost of making the refuse-manure.—Both refuse and sewage are waste materials which have to be removed from populated areas and it follows that whether converted into manure or not, the refuse must be collected and transported. The cost of making the refuse-manure should therefore normally be only that of labour, and machinery for treating the refuse with sewage, chemicals or other materials to facilitate decomposition at the place of treatment. Observations on the experimental heaps have already shown that addition of chemical starters is unnecessary and indeed wasteful. The cost of making the manure therefore reduces itself to that of (*a*) spraying with sewage, and (*b*) treating with insecticides, fungicides or other substances to eliminate odour and suppress putrefactive and pathogenic organisms.

Assuming that the heaps are arranged in a row or a continuous chain and that coolies provided only with buckets and watering cans are available, it may be expected that each cooly can maintain at least 40 tons of refuse sufficiently moist for continuous decomposition. Our observations have shown that the decomposition is complete in about two months, but allowing a margin of a fortnight and reckoning that the cooly is paid 8 As. (9*d.*) a day, it may be calculated the total average cost of spraying a ton of refuse would be

15 As. The cost of copper sulphate required for spraying one ton of refuse would be less than half an anna and that of lime about one anna. The total cost of treatment would therefore be about one rupee (18*d.*) per ton of refuse. There would no doubt be shrinkage in dry matter to the extent of about 20 per cent., but the finished product generally contains an equivalent amount of extra moisture so that the final weight of the manure would be about the same as that of initial refuse. It may be reckoned therefore that the cost price of the manure would be about one rupee per ton.

The composition and the price paid for farmyard-manure vary from place to place, and are determined by several factors such as the number and feed of farm animals or local demand. It may be assumed, however, that the average type of farmyard-manure available in India contains about 0·7 per cent. nitrogen and fetches about Rs. 5 per ton, whence it follows that the refuse-manure which is rich in nitrogen (about 1 per cent.) and has been shown to possess a greater manurial value would be worth more than Rs. 5 a ton. Since refuse-manure can be made at about Re. 1 per ton, it can be sold at less than half the price of farmyard-manure and still show ample profit.

In large cities where the volume of refuse is considerable and where power is easily available, it would be cheaper and indeed more efficient to spray the sewage by machinery. Devices for spraying are already known and adopted in sewage practice, so that with the introduction of the necessary equipment large volumes of sewage and refuse can be dealt with at far less cost than when employing man-power alone. In European countries, particularly Great Britain, where farmyard-manure costs 4-5 times as much as it does in India and where machine-power is cheaply available, it would be highly profitable to convert all the available refuse into manure, and so meet the growing demand from those engaged in glass-house industries, market-gardening and fruit-farming.

Experiments in composting refuse with night-soil.—The problems connected with the utilisation of night-soil in India resemble those in China and Japan, night-soil being removed by a system of hand conservancy and subsequently distributed; in China and Japan after decomposition in special cisterns or underground pits, and in India generally by direct application to land. Both systems are unsatisfactory hygienically. The Chinese method though preferable agriculturally is insanitary from smell and water-pollution. The Indian method is also defective, but the night-soil being merely heaped on the fields offers less danger of water-pollution than in China. Moreover, the use of unmixed night-soil leads to considerable wastage of nitrogen, owing to its high proportion of nitrogen to carbon.

Fowler (*Surveyor*, 1927, **71**, 259) suggested that night-soil may be dumped on refuse heaps and the mixture turned frequently so as to facilitate ærobic decomposition. In a later publication (*Agric. Jour. India.*, 1930, **25**, 363), he described experiments at Nasik where night-soil was used both as the source of nitrogen and as the requisite biological activator, obtaining a well-rotted manure in a few weeks.

Some preliminary experiments were conducted to determine the effect of adding night-soil in small instalments to refuse heaps, one gallon per heap (500 lbs.) of refuse: the heaps were then turned and moistened with raw sewage at the rate of 20 gals. per heap. It was found difficult, however, thoroughly to mix the night-soil with the heap, and after about 25 days the difficulty increased, unpleasant odours being emitted when the heaps were stirred. Spraying with copper-lime mixture or bleaching powder suppressed the smell, but only temporarily. It was easier and more hygienic to suspend the night-soil in sewage and then distribute the liquid over the heap.

Night-soil (2 gals.) was stirred into 12 gals. of raw sewage in a covered drum of about 25 gals. capacity. After 10 days the contents were homogeneous and in spite of some odour could be handled with ease. A portion was transferred to another drum, mixed with 10 times its volume of raw sewage, and then applied to the refuse heaps. To the residue in the first drum, more night-soil was added and liquefaction allowed to proceed as before, being complete within 24 hours; a portion was removed and applied to the refuse heaps after dilution with raw sewage in the manner described already. The processes of liquefaction, dilution and spraying were repeated from day to day without experiencing any further difficulty.

The sprayed heaps were (*a*) entirely of refuse and (*b*) half refuse, and half mixed waste vegetation, mostly lantana (*Lantana camara*) leaves. The heaps of refuse alone weighed about 240 lbs. each while those mixed with waste vegetation weighed about 480 lbs. each and were all treated with lime corresponding to 1 per cent. on the dry weight. One heap weighing 240 lbs. was used as control and sprayed only with 18 gals. of water per day. Heaps under *a* were sprayed with night-soil emulsion (prepared in the manner described above) at the rate of 6 gals. per day and those under *b* at double that rate. It was soon found, however, that the above-mentioned quantities did not provide sufficient moisture to facilitate rapid decomposition, and therefore 12 and 24 gals. respectively of raw sewage per day were used. Each heap was stirred twice a day and sprayed with minute quantities of copper-lime mixture or bleaching powder suspension whenever there was a pronounced smell; but the insecticides and fungicides were needed only occasionally, and there was normally no foul odour from any of the heaps. The contents of the drum used for liquefying night-soil were somewhat objectionable particularly after fresh additions.

The foregoing observations, though essentially preliminary in character, have brought out important facts relating to the utilisation of night-soil with sewage in composting refuse. Preliminary liquefaction of night-soil is essential to its adequate admixture with the refuse, and although initially the active liquefying flora are slow to establish themselves, subsequent liquefaction proceeds at a rapid rate thus facilitating the utilisation of liquefied night-soil within the 24 hours after collection; but the technique of dilution and application requires further improvement.

It was observed that the liquefied and diluted night-soil as applied to the refuse heaps contained on an average 52 parts of nitrogen per 100,000. This was very considerable as compared with raw sewage, and it was expected that the final product would be richer in nitrogen than the heaps sprayed with raw sewage alone. The decomposition of the heaps treated with night-soil emulsion was allowed to proceed for two months when appreciable change in dry matter had ceased; the products were removed, dried and analysed for the various fertilising ingredients, the percentage composition of the different preparations on the oven-dry basis being given in Table IX.

TABLE IX.

Manure from	Nitrogen				Availability	
	Total	Ammonia	Nitrate	Albuminoid	P_2O_5	K_2O
Refuse+waste vegetation*	0·90	0·03	0·22	0·35	2·54	0·27
Refuse only*	0·92	0·02	0·15	0·32	0·60	0·37
Refuse sprayed with water only	0·46	0·01	0·11	0·21	0·33	0·13
Farmyard-manure	0·72	0·02	0·11	0·27	0·30	0·40

* Treated with night-soil emulsion and sprayed with sewage.

It is seen that although the manure prepared by composting refuse with night-soil is richer in various fertilising ingredients than farmyard-manure, it is not greatly superior to most of those previously obtained by spraying raw sewage alone on refuse. The product obtained from the mixture of refuse and waste vegetation is, however, distinguished from the others by its richness in available phosphoric acid, which it contains to the extent of over four times that of any of the heaps so far examined. Since those heaps were identical with the others except in that they were half waste vegetation it may be inferred that the increased phosphorus content was derived from that component.

A study of the nitrogen balance shows that the loss of nitrogen was more marked in the case of heaps treated with night-soil emulsion than in those sprayed with raw sewage alone. The results of the present experiment indicate that the loss corresponds to about 23 lbs. of nitrogen per ton of finished product. This suggests that in addition to standardising conditions for the application of night-soil emulsion to the refuse attempts should also be made to minimise the loss of nitrogen occurring under such conditions.

The foregoing observations also show that when supply of refuse is inadequate for being composted with the available amount of night-soil it can be advantageously mixed with waste vegetation so as to obtain a suitable finished product. As the chemical composition of the waste vegetation used for the experiments had not been previously determined, it is difficult to state whether the loss of nitrogen was greater in their presence than in refuse alone. Further work is needed to elucidate the above and related problems.

Vegetation experiments with manure prepared from night-soil and refuse.—To compare the relative manurial values of (1) manure prepared by composting refuse with night-soil. (2) farmyard-manure, and (3) the product obtained by spraying refuse with water, pot-culture experiments were made with ragi in the manner described already. Growth measurements were taken at various stages and Table X shows the results obtained on the 52nd day after sowing.

TABLE X.

Manure	Root-length in cms.	Shoot-height in cms.	Root-wt. in g.	Shoot-wt. in g.
Refuse (night-soil)	57	57·5	0·97	2·40
Farmyard-manure	54	46·5	0·47	1·80
Refuse (water)	56·5	43·5	0·40	0·97

As distinguished from the observations made in the earlier set of experiments, it was also noted that the plants raised on refuse (night-soil) manure had a larger root-system in addition to having bigger and richer tops. Since it is known that phosphates are generally helpful to root development and since the night-soil treated manure is richer in phosphorus than the preparation sprayed with sewage, it is possible that the increased root development was due to a larger amount of that element in the former.

Plot experiments.—Field experiments were made with (1) night-soil treated manure and (2) farmyard-manure, to compare their relative manurial values and to determine the efficacy of giving basal dressing of superphosphate on crop yield. The areas of the plots, and their distribution were identical with those described in an earlier experiment. The total area under each treatment was 300 sq. ft. and the two manures were added on equivalent nitrogen basis, farmyard-manure being taken as the standard and applied at 25 tons to the acre. After allowing the soil to rest for a week, superphosphate (concentrated) was added at 4 cwts. to the acre and after a further rest, the plots were sown with ragi seedlings as in the previous trials. After about three months, the crop was harvested and the yields of grain and straw determined.

TABLE XI.

Total Yields.

Manure	Straw		Grain	
	lbs.	oz.	lbs.	oz.
Refuse-manure ..	41	8	12	14
Farmyard-manure ..	24	8	8	0

The above results bear testimony to (*a*) the distinct superiority of the refuse-manure to farmyard-manure and (*b*) the efficacy of superphosphate applied in combination with the refuse-manure in increasing crop yield. It should, however, be noted that the rates at which the manures were applied, in the above and the previous trials were larger than those commonly adopted in Indian agricultural practice. Further experiments should be carried out to determine the optimum dosage of the phosphate as well as the organic component.

Experiments on composting with activated sludge.—Although the manurial value of activated sludge has long been recognised, its application in agricultural practice has been greatly handicapped by difficulties connected with de-watering. Fresh sludge contains nearly 98 per cent. of water and retains it tenaciously unless treated with acids, electrolytes or heat. Applying the above principles, much work has been done by various workers in America (Martin, Activated Sludge Process, 1927, 326-347) and by Fowler in India. The cost of de-watering appears to be rather high compared with the sale-value of the fertiliser. In view of the above and other difficulties attending the de-watering of sludge, several workers have preferred the digestion process: this yields fuel gases and an inoffensive, tarry residue, but is wasteful and results in loss of valuable fertilising ingredients.

Consequently, since refuse heaps readily abstract water from sewage sludges, fresh activated sludge (2 litres) was added to refuse (8 lbs.) and the daily changes noted. Control experiments were also carried out by leaving similar lots of activated sludge to undergo spontaneous evaporation in shallow containers. It was observed that whereas the treated refuse absorbed all the sludge and underwent rapid decomposition accompanied by development of an earthy odour and steady loss of moisture, the sludge left in containers soon underwent septic action accompanied by foul odours but no marked loss of moisture. Determinations of moisture content of treated refuse at intervals gave the following results:—

Day	Moisture per cent.	Day	Moisture per cent.
1	73·9	10	25·0
5	55·2	12	13·4
6	35·8	14	11·1

The results show that although the dehydration is not immediate, it proceeds steadily, and the cost would be very small. The final product would have increased manurial value from the fertilising ingredients of both activated sludge and refuse.

Summary.

In presence of mineral starters neither the rate of decomposition nor the manurial value of refuse composted with sewage is appreciably improved.

Owing to inadequate æration and other reasons the heaps tend to smell occasionally, but normal conditions may be rapidly restored by spraying the heaps with either thin Bordeaux mixture or bleaching powder suspension, the former being cheaper and more efficient.

Under normal conditions, there is marked loss of nitrogen from the decomposing heaps approximating to 2 lbs. on the preparation of each ton of manure. In presence of activated sludge, however, there is an increase in total nitrogen suggesting fixation of that element from the atmosphere.

Vegetation experiments have shown that the organic manures prepared from refuse are generally superior to farmyard-manure and more effective than combined chemical fertilisers. As in most cases, the value of the manure appears to be enhanced by superphosphate. The residual value of the refuse-manure is also higher than that of farmyard-manure and other fertilisers tested.

The possibilities of the refuse-manure industry have been discussed. Even in absence of machine-power for spraying the sewage, the cost of making the manure is about one-fifth of the price of comparatively inferior farmyard-manure. The cost could be further reduced by employing machine-power and by so adjusting the proportion of sewage or night-soil to refuse and ensuring adequate air-supply that the need for spraying with chemicals to suppress odour becomes unnecessary. The supply of raw material is enormous, the annual collection of refuse being over 20 million tons in India alone. It could also be supplemented by combining the refuse with waste vegetation.

Marked change in the composition of the microflora concerned in the decomposition is brought about by spraying the heaps with the copper mixture. *Actinomyces* are greatly encouraged while fungi are suppressed. The change in the microflora does not, however, affect either the rate of decomposition or the manurial value of the final product.

Experiments on composting with night-soil have shown that it would be necessary partially to liquefy the material and then dilute it with sewage to ensure adequate distribution over the heaps. With proper æration, the decomposition proceeds rapidly, but the loss of nitrogen is greater than in the case of heaps treated with sewage alone.

By mixing activated sludge with refuse it may be possible to reduce the water-content of the former and at the same time facilitate the decomposition of the latter.

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Department of Biochemistry,
Indian Institute of Science,
Bangalore.

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